MODERN FUZZY MIN MAX NEURAL NETWORKS FOR PATTERN CLASSIFICATION

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy/Master of Science/Master of Engineering

Faculty of Computer Systems & Software Engineering
UNIVERSITI MALAYSIA PAHANG

AUGUST 2019

ACKNOWLEDGEMENTS

First of all, many thanks to my supervisor, Dr. Mohammad Falah Mohammad for his great patience and knowledgeable guidance during the past three years PhD study. His professional research experience teaches me how to be creative, how to find problems and solve them. His active attitude of life encourages me working hard towards my destination. In addition, I would like to thank him for improving and polishing my writing skills. I would like to express the deepest appreciation also for Dr. Liew Siau Chun for advising support.

My distinctive thanks to my beloved wife- Eng.Abeer binti Moh'd; you were a complete package of family and love me strength, support, and love during tough times. My daughter Retan and son Aws, you are my world, my words, my strength. Thank you

I am greatly grateful to my parents, Mr. Nayel bin Ahmad, Ibtehaj binti Abdullah, for their endless love, unconditional support, and encouragement through all these years. I am also thankful to my sisters and my brothers, Eng.Ansam, Ashwaq, Dr. Wasn, Dr. Mohammed, Dr. Ehab, and Dr. Anas for their support during many years of my studies.

Finally, I would like to thank all staff at the faculty of Computer Systems & software Engineering, University of Malaysia Pahang for their support.

ABSTRAK

Kebelakangan ini, terdapat tumpuan yang mendalam terhadap kaedah pengkomputeran lembut bagi mengatasi masalah dunia sebenar yang kompleks. Rangkaian neural dan logik kabur merupakan antara kaedah pengkomputeran lembut yang sering digunakan dalam bidang klasifikasi corak. Dalam membina sebuah model pengelas yang berkesan, para penyelidik memperkenalkan model hibrid yang menggabungkan kedua-dua logik kabur dan rangkaian neural buatan. Antara algoritma yang diperkenalkan, algoritma rangkaian neural Min-Max Kabur (FMM) terbukti sebagai salah satu rangkaian neural terulung dalam mengatasi masalah klasifikasi corak. FMM mempunyai pelbagai fitur penting, berkebolehan untuk menyediakan proses pembelajaran dalam talian dan menangani masalah kelupaan. Namun sedemikian, algoritma ini turut menghadapi beberapa batasan, khususnya dalam proses pembelajarannya, iaitu proses pengembangan, proses ujian bertindih dan proses pengecutan. Oleh itu, rangkaian neural Min-Max Kabur Moden (MDFMM) diperkenalkan dengan tujuan mengatasi batasan-batasan FMM asal. MDFMM membawa kepada beberapa sumbangan seperti mengubah suai fungsi pengaktifan pengembangan FMM asal dan menggantikannya dengan Min-Max Kabur Tertingkat (EFMM) untuk menyingkirkan kes bertindih. Pertama, kajian ini mencadangkan kaedah pengembangan baru untuk mengatasi masalah kelonggaran dan ketaksamaan pengembangan hiperboks yang bertindih. Akibatnya, kaedah ini dapat mengurangkan proses pengecutan. Kedua, kajian ini mengusulkan satu formula ujian bertindih baru yang mempermudahkan proses ujian bertindih FMM/EFMM dengan meliputi semua kes bertindih yang mungkin dengan sempurna. Ketiga, kajian ini mencadangkan satu proses pengecutan baru yang memberikan gambaran hiperboks yang lebih tepat dan menghindari masalah herotan data (kehilangan maklumat hiperboks). Keempat, kajian ini mengusulkan strategi ramalan baru dalam fasa ujian dengan menyepadukan persamaan jarak bersama fungsi keahlian untuk menangani masalah pembuatan keputusan rawak. Strategi ini dapat membantu untuk memberikan ramalan yang lebih tepat ketika sampel input mempunyai nilai kesesuaian yang sama dengan kelas lain. Bagi mengatasi kerumitan struktur rangkaian MDFMM, satu penambahbaikan diperkenalkan dengan meningkatkan pemilihan hiperboks yang menang dalam proses pengembangan menggunakan algoritma k-terdekat. Model cadangan baru dinamakan sebagai MDFMM-Kn. Prestasi MDFMM dan MDFMM-Kn dinilai menggunakan pelbagai set data tanda aras UCI dan set data kecerdasan buatan 2D. Di samping itu, tiga kaedah analisis statistik, iaitu kaedah bootstrap, pengesahsahihan silang k-fold dan ujian taraf bertanda Wilcoxon, digunakan untuk menyatakan kuantiti prestasi secara statistik. Berdasarkan penilaian empirik, MDFMM yang dicadangkan didapati lebih baik berbanding model sedia ada (rangkaian neural Min-Max Kabur Ubah Suai, atau MFMMN) dari segi ketepatan dengan peratusan peningkatan sebanyak 35.42%. Tambahan pula, prestasi purata MDFMM-kn berbanding model FMM dan MDFMM menunjukkan prestasi yang lebih baik dari segi kerumitan dengan peratusan sebanyak 62%.

ABSTRACT

In the recent years, the world has demonstrated an increasing interest in soft computing techniques to deal with complex real world problems. Neural network and fuzzy logic are considered to be one of the most popular soft computing techniques that applied in pattern classification domain. To build an efficient classifier model, researchers have introduced hybrid models that combine both fuzzy logic and artificial neural networks. Among these algorithms, Fuzzy Min Max (FMM) neural network algorithm has been proven to be one of the premier neural networks for undertaking the pattern classification problems. Although the FMM has many important features with the ability to provide online learning process and can handle the forgetting problem, it suffers from a number of limitations, especially in its learning process i.e., expansion process, overlapping test process, and contraction process. Therefore, Modern Fuzzy Min Max neural network is introduced with aim of overcoming the specified limitations of the original FMM. The MDFMM introduces a number of contributions in addition to modify the original FMM expansion activation function by replace it with that from the Enhanced Fuzzy Min Max (EFMM) to eliminate the overlapping cases. First, this study proposed a new expansion technique to overcome both overlap leniency and irregularity of hyperbox expansion problems, as a result, reducing the number of contraction processes. Secondly, proposing a new overlapping test formula that simplify the FMM/EFMM overlap test process with perfectly covers all the possible overlapped cases. Thirdly, proposing a new contraction process that provides more accurate hyperboxes description and avoid data distortion problem (hyperbox information losses). Fourthly, proposing a new prediction strategy in the test phase by integrating the distance equation with membership function in order to solve the randomization decision making problem, which helps to provide more accurate prediction when input sample has same fitness values with different classes. To overcome the network structure complexity of MDFMM, a further improvement is introduced by improving the selection of the winning hyperbox during the expansion process using the k-nearest neighbours algorithm (MDFMM-Kn). The performance of MDFMM and MDFMM-Kn was evaluated using different UCI benchmark datasets and 2D artificial intelligence dataset. Furthermore, three statistical analysis techniques, namely, bootstrap method, k-fold cross-validation and the Wilcoxon signed-rank test, were utilized to statistically quantify the performances. From the empirical evaluation, the proposed MDFMM is better than the recent existing model modified FMM network (MFMMN) in terms of accuracy at an improvement percentage of 35.42%. Furthermore, the average performance of the MDFMM-Kn against the FMM and MDFMM models is better than that of the existing techniques in terms of complexity at a percentage of 62%.

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θ	User defined expansion parameter
Δ	Value of overlap
γ	Sensitive parameter

LIST OF ABBREVIATIONS

AFMN	Adaptive Fuzzy Min Man Neural
AI	Artificial Intelligence
ANN	Artificial Neural Network
ART	Adaptive Reasoning Theory
CLN	Classify Neuron
CNN	Containment Compensation Neuron
DCFMN	Data Core Fuzzy Min Max Neural Network
EFC	Inclusion/Exclusion Fuzzy Classifier
EFMM	Enhanced Fuzzy Min Max
EGFMM	Enhanced General Fuzzy Min Max
ES	Evolutionary Strategies
FAM	Fuzzy ARTMAP
FMCN	Fuzzy Min Max Compensatory neurons
FL	Fuzzy Logic
FMM	Fuzzy Min Max
MFMM-GA	Modified Fuzzy Min Max – Genetic Algorithm
FMM-KN	Fuzzy Min Max- Key Nearest
FNN	Fuzzy Neural Network
GA	Genetic Algorithm
GFMM	General Fuzzy Min Max
GP	Genetic Programming
GRFMN	General Reflex Fuzzy Min Max Neural
MDFMM	Modern Fuzzy Min Max
MDFMM-Kn	Modern Fuzzy Min Max Enhanced Key Nearest
M-FMCN	Modified- Fuzzy Min Max Compensatory neural
MFMM1	Modified Fuzzy Min Max 1
MFMM2	Modified Fuzzy Min Max 2
MFMM-GA	Modified Fuzzy Min Max with genetic algorithm
MFMMN	Modified Fuzzy Min Max Neural Network
MLF	Multilevel Fuzzy
MLP	Multi-Layer Perceptron

NFS	Neuro Fuzzy Systems
OCN	Overlap Compensation Neuron
OCR	Optical Character Recognition
PR	Pattern Recognition
RBFN	Radial Basis Function Network
SLP	Single Layer Perceptron
WFMM	Weighted Fuzzy Min Max

REFERENCES

Alan, M. (1950). Turing. Computing machinery and intelligence. Mind, 59, 433-460.

Andrzej Bargiela 1, M. T., Giovanna Castellano 3, Annamaria Fanelli 3. (2004). Adaption of exclusion/inclusion hyperboxes. *CEUR Workshop Proceedings*, 1542, 33-36.

Augasta, M. G., & Kathirvalavakumar, T. (2013). Pruning algorithms of neural networks—a comparative study. *Central European Journal of Computer Science*, 3(3), 105-115.

Azad, C., & Jha, V. K. (2017). Fuzzy min–max neural network and particle swarm optimization based intrusion detection system. Microsystem Technologies, 23(4), 907-918.

Azad, C., Mehta, A. K., & Jha, V. K. (2018). Improved Data Classification using Fuzzy Euclidean Hyperbox Classifier. *Paper presented at the 2018 International Conference on Smart Computing and Electronic Enterprise*.

Bache, K., & Lichman, M. (2013). UCI machine learning repository.

Barde, N. C., & Patole, M. (2016). Classification and Forecasting of Weather using ANN, k-NN and Naïve Bayes Algorithms. *International Journal of Science and Research (IJSR)*, 5(2), 1740-1742.

Bargiela, A., Pedrycz, W., & Tanaka, M. (2004). An inclusion / exclusion fuzzy hyperbox classifier. *KES Journal*, 8, 91-98.

Begum, S. A., & Devi, O. M. (2011). Fuzzy Algorithms for Pattern Recognition in Medical Diagnosis. Assam University *Journal of Science and Technology: Physical Sciences and Technology*, 7(2), 1-12.

Carpenter, G. A., & Grossberg, S. (1987). A massively parallel architecture for a self-organizing neural pattern recognition machine. *Computer vision, graphics, and image processing*, 37(1), 54-115.

Carpenter, G. A., Grossberg, S., & Reynolds, J. H. (1991a). ARTMAP: supervised real-time learning and classification of nonstationary data by a self-organizing neural network. *1991 IEEE Conference on Neural Networks for Ocean Engineering*, 4, 341-342.

Carpenter, G. A., Grossberg, S., & Rosen, D. B. (1991b). Fuzzy ART: an adaptive resonance algorithm for rapid, stable classification of analog patterns. *1991 Seattle International Joint Conference on Neural Networks*, 2(6), 411-416.

Davtalab, R., Dezfoulian, M. H., & Mansoorizadeh, M. (2014). Multi-level fuzzy min-max neural network classifier. *IEEE Transactions on Neural Networks and Learning Systems*, 25(3), 470-482.

Donglikar, N. V., & Waghmare, J. M. (2017). An enhanced general fuzzy min-max neural network for classification. *Paper presented at the 2017 International Conference on Intelligent Computing and Control Systems*. 757-764

Duan, Y., Cui, B., & Xu, X. (2007). State space partition for reinforcement learning based on fuzzy min-max neural network. *Paper presented at the 2007 International Symposium on Neural Networks*. 160-169

Fallahnezhad, M., Moradi, M. H., & Zaferanlouei, S. (2011). A Hybrid Higher Order Neural Classifier for handling classification problems. *Expert Systems with Applications*, 38(1), 386-393.

Gabrys, B., & Bargiela, A. (2000). General fuzzy min-max neural network for clustering and classification. *IEEE Transactions on Neural Networks*, 11, 769-783.

Gao, Z., Cecati, C., & Ding, S. X. (2015). A Survey of Fault Diagnosis and Fault-Tolerant Techniques—Part I: Fault Diagnosis With Model-Based and Signal-Based Approaches. *IEEE Transactions on Industrial Electronics*, 62(6), 3757-3767.

Genaro, N., Torija, A., Ramos, A., Requena, I., Ruiz, D. P., & Zamorano, M. (2009). Modeling Environmental Noise Using Artificial Neural Networks. *Paper presented at the 2009 Ninth International Conference on Intelligent Systems Design and Applications*. 215-219

Hau, C. C. (2015) Handbook of Pattern Recognition and Computer Vision: World Scientific. 1-1044.

Jain, A. K., Duin, R. P. W., & Jianchang, M. (2000). Statistical pattern recognition: a review. I*EEE Transactions on Pattern Analysis and Machine Intelligence*, 22(1), 4-37.

Jang, J. S. R. (1993). ANFIS: adaptive-network-based fuzzy inference system. *IEEE Transactions on Systems, Man, and Cybernetics*, 23(3), 665-685.

Jawarkar, N., Holambe, R., & Basu, T. (2011). Use of fuzzy min-max neural network for speaker identification. *Paper presented at the 2011 International Conference on Recent Trends in Information Technology*.178-182

Kamruzzaman, S. M., & Jehad Sarkar, A. M. (2011). A new data mining scheme using artificial neural networks. *Sensors*, 11(5), 4622-4647.

Keller, J. M., & Hunt, D. J. (1985). Incorporating fuzzy membership functions into the perceptron algorithm. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 7 (6), 693-699.

Kim, H.-J., Ryu, T.-W., Lee, J., & Yang, H.-S. (2006). Face detection using an adaptive skin-color filter and FMM neural networks. *Paper presented at the 2006 9th Pacific Rim international conference on Artificial intelligence*.4099, 1171-1175.

Kim, H. J., Ryu, T. W., Nguyen, T. T., Lim, J. S., & Gupta, S. (2004). A Weighted Fuzzy Min-Max Neural Network for Pattern Classification and Feature Extraction. Paper presented at the *2004 Computational Science and Its Applications*, 3612,1178-1181

Kim Hua, T., Chee Peng, L., Hooi Shen, K., & Platts, K. (2004). Application of the fuzzy ARTMAP neural network to classification of manufacturing technology projects. *WSEAS Transactions on Computers*, 3(3), 636-641.

Kuan, M. M., Lim, C. P., & Harrison, R. F. (2003). On operating strategies of the fuzzy ARTMAP neural network: A comparative study. *International Journal of Computational Intelligence and Applications*, 3(01), 23-43.

Liu, H., Yin, J., Luo, X., & Zhang, S. (2018). Foreword to the special issue on recent advances on pattern recognition and artificial intelligence. *Neural Computing and Applications*, 29(1), 1-2.

Liu, J., Yu, Z., & Ma, D. (2012). An adaptive fuzzy min-max neural network classifier based on principle component analysis and adaptive genetic algorithm. *Mathematical Problems in Engineering*, 2012.

Mermillod, M., Bugaiska, A., & Bonin, P. (2013). The stability-plasticity dilemma: investigating the continuum from catastrophic forgetting to age-limited learning effects. *Frontiers in Psychology*, 4, 1-3.

Mithe, R., Indalkar, S., & Divekar, N. (2014). Optical character recognition. *International Journal of Emerging Technology and Advanced Enginnering*, 4(5), 219-223.

Mohammed, M. F., & Lim, C. P. (2015). An enhanced fuzzy min-max neural network for pattern classification. *IEEE Transactions on Neural Networks and Learning Systems*, 26(3), 417-429.

Mohammed, M. F., & Lim, C. P. (2017a). Improving the Fuzzy Min-Max neural network with a K-nearest hyperbox expansion rule for pattern classification. *Applied Soft Computing*, 52, 135-145.

Mohammed, M. F., & Lim, C. P. (2017b). A new hyperbox selection rule and a pruning strategy for the enhanced fuzzy min–max neural network. Neural networks, 86, 69-79.

Nandedkar, A. V., & Biswas, P. K. (2007a). A fuzzy min-max neural network classifier with compensatory neuron architecture. *IEEE Transactions on Neural Networks*, 18, 42-54.

Nandedkar, A. V., & Biswas, P. K. (2007b). A General Reflex Fuzzy Min-Max Neural *Network. Engineering Letters*, 14, 195-205.

Naz, S., Hayat, K., Imran Razzak, M., Waqas Anwar, M., Madani, S. A., & Khan, S. U. (2014). The optical character recognition of Urdu-like cursive scripts. Pattern recognition, *Pattern Recognition* ,47(3), 1229-1248.

Oludolapo, O. A., Jimoh, A. A., & Kholopane, P. A. (2012). Comparing performance of MLP and RBF neural network models for predicting South Africa's energy consumption. *Journal of Energy in Southern Africa*, 23(3), 40-46.

Pal, S. K., & Mitra, S. (1992). Multilayer perceptron, fuzzy sets, and classification. *IEEE Transactions on Neural Networks,* 3(5), 683-697.

Pawar, D. (2015). Fuzzy min-max neural network with compensatory neuron architecture for invariant object recognition. *Paper presented at the 2015 International Conference on Computer, Communication and Control* (IC4). 1-5

Qu, Z. (2009). Application of Data Mining in Classification Analysis of Safety Accidents Based on Alternate Covering Neural Network. *Paper presented at the 2009 International Conference on Innovation Management*. 47-50.

Quteishat, A., Al-Batah, M., Al-Mofleh, A., & Alnabelsi, S. H. (2013). Cervical cancer diagnostic system using adaptive fuzzy moving k-means algorithm and fuzzy min-max neural network. *Journal of Theoretical and Applied Information Technology*, 57(1), 48-53.

Quteishat, A., & Lim, C. (2007). A modified fuzzy min-max neural network and its application to fault classification. *Soft computing in industrial applications*,39 ,179-188.

Quteishat, A., & Lim, C. P. (2008). A modified fuzzy min-max neural network with rule extraction and its application to fault detection and classification. *Applied Soft Computing*, 8(2), 985-995.

Quteishat, A., Lim, C. P., & Tan, K. S. (2010). A modified fuzzy min–max neural network with a genetic-algorithm-based rule extractor for pattern classification. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, 40(3), 641-650.

Raj, M., Swaminarayan, P., Saini, J., & Parmar, D. (2015). Applications of Pattern Recognition Algorithms in Agriculture: A Review. *International Journal of Advanced Networking and Applications,* 6(5), 2495-2502.

Reaz, M. B., Hussain, M., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: detection, processing, classification and applications. *Biological procedures online,* 8(1), 11-35.

Saksamudre, S. K., Shrishrimal, P., & Deshmukh, R. (2015). A review on different approaches for speech recognition system. *International Journal of Computer Applications*, 115(22), 23-28.

Seera, M., & Lim, C. P. (2014). Online motor fault detection and diagnosis using a hybrid FMM-CART model. *IEEE Transactions on Neural Networks and Learning Systems*, 25(4), 806-812.

Seera, M., Lim, C. P., Ishak, D., & Singh, H. (2013). Application of the fuzzy min–max neural network to fault detection and diagnosis of induction motors. *Neural Computing and Applications*, 23(1), 191-200.
Shinde, S., & Kulkarni, U. (2016). Extracting classification rules from modified fuzzy min–max neural network for data with mixed attributes. *Applied Soft Computing*, 40, 364-378.

Shrivastava, J. N., & Bindu, M. H. (2014). E-mail Spam Filtering Using Adaptive Genetic Algorithm. *International Journal of Intelligent Systems and Applications*, 6(2), 54-60.

Simpson, P. K. (1992). Fuzzy min-max neural networks. I. Classification. *IEEE Transactions on Neural Networks*, 3(5), 776-786.

Simpson, P. K. (1993). Fuzzy min-max neural networks-part 2: Clustering. IEEE Transactions on Fuzzy systems, 1(1), 32-45.

Smola, A., & Vishwanathan, S. (2008). Introduction to machine learning. Cambridge University, UK, 32, 1-34.

Tkáč, M., & Verner, R. (2016). Artificial neural networks in business: Two decades of research. *Applied Soft Computing*, 38, 788-804.

Umoh, U. A. U., A.A.; James, G.G.; oton, U.U.; Udoudo, J.J.; B.Eng. (2012). Design of Pattern Recognition System for the Diagnosis of Gonorrhea Disease. *International Journal of Scientific & Technology Research*, 1(5), 74-79.

Unar, J., Seng, W. C., & Abbasi, A. (2014). A review of biometric technology along with trends and prospects. *Pattern recognition*, 47(8), 2673-2688.

Upasani, N., & Om, H. (2018). Optimized fuzzy min-max neural network: an efficient approach for supervised outlier detection. *Neural Network World*, 28(4), 285-303.

Viharos, Z. J., & Kis, K. B. (2015). Survey on neuro-fuzzy systems and their applications in technical diagnostics and measurement. *Measurement*, 67, 126-136.

Yilmaz, I., Erik, N. Y., & Kaynar, O. (2010). Different types of learning algorithms of artificial neural network (ANN) models for prediction of gross calorific value (GCV) of coals. *Scientific Research and Essays*, 5, 2242-2249.

Yilmaz, I., & Kaynar, O. (2011). Multiple regression, ANN (RBF, MLP) and ANFIS models for prediction of swell potential of clayey soils. *Expert Systems with Applications*, 38, 5958-5966.

Zhang, H., Liu, J., Ma, D., & Wang, Z. (2011). Data-core-based fuzzy min–max neural network for pattern classification. *IEEE Transactions on Neural Networks*, 22(12), 2339-2352.